

THE REALITY OF DESIGN PROCESS PLANNING

C M Eckert and P J Clarkson

Abstract

Most companies struggle with the efficiency of their processes. One contributory factor is the lack of efficient process planning. This paper describes current planning practise in industry, which uses a multitude of different plans in parallel. The units of planning and their resulting plans roughly fall into product plans considering cost, bill of material and procurement considerations; process plans including different milestone, task and activity plans and quality plans. This paper maps out the ownership of these plans, and establishes that organisations work because individuals use more than one plan and have a tacit understanding of the relationships between these plans. The lack of effective plans affects the company through a lack of understanding of process connectivity and in consequence bad communication.

Keywords: complexity management, design management, project-management

1 Introduction

Companies are fully aware that it is vital to bring design projects to a successful completion on time to assure financial viability and secure the long-term survival of the company [1]. There is also increasing awareness of the importance of a properly conceived design process. However, whether a process will succeed also depends on how well it is planned for each project. At present there is little understanding in industry and academia of how industrial processes are planned and how they could be planned more efficiently. This paper, based on four industrial case studies, presents a description and analysis of how design processes are planned in industry.

Each case study involved between 15 and 25 one hour interviews with designers and design managers, as illustrated in Table 1. Each interview was approached with a set of detailed questions, but interviewees are encouraged to speak freely. The interviews were complemented by observations lasting several days in each the companies. All the interviews were recorded and subsequently transcribed. They were analysed and presented back to the interviewees and their managers. This feedback initiated serious reflection within each company about the efficiency of their processes.

The general findings were discussed with senior designers and design managers from other UK and German companies. All the companies involved design highly complex products. With the exception of some of the consultancy projects and some minor change projects, all the projects involved significant project and process innovation. All companies pointed out, that they now work to reduced time scales compared to similar projects in the past. These companies are not a statistically significant sample, but we have no reason to assume that they are not typical for design companies with non-repeatable processes.

Academic research on planning methods has a long tradition in artificial intelligence, workflow planning and manufacturing planning, for optimising repeatable processes. Design research has concentrated on developing tools to support design process planning (see for example [2] for a review of the Design Structure Matrix research on planning), however these rarely include detailed description of industrial planning practise beyond motivations for particular methods (e.g. [3]). This papers aims to provide insights into the complexity of planning behaviour occurring in companies at present, which is pertinent to the development of such methods and tools, as illustrated in section 4.

Table 1. The case studies

Year	Interviews	Focus	No. of engineers	Industry sector	Comment
1999	22	change	400	aerospace	Main activity: tendering and planning of customisation
2000	18	planning and communication	120	automotive	New project, new people, no established company procedure
2002	17	planning and communication	40	automotive consultancy	Change from internal funding to consultancy, 40 designers, 100s of projects
2002	20	change	200	engines	Planning new product develop and numerous versions

2 Planning Behaviour

All the organisations we studied had many plans at the same time and none had one master plan that covered all aspects of a project in detail. Everybody planned a particular aspect of a project to satisfy their individual needs. Successful completion of projects was assured because most individuals were using more than one plan at any one time. We can distinguish between process plans, which tried to ensure that the project is finished on time and product plans, which aim to ensure that the product meets its target product cost. Quality procedures seemed to be very disjointed in the organisations that we studied.

2.1 Understanding of processes

All design managers we discussed the issue with complained bitterly – with some justification – that their designers only ever want to get stuck into designing and not worry about processes. They want to keep on designing until they are satisfied at every stage and not worry about cost or deadlines. Designers, rather than design managers, often have little awareness of the process that they are involved in; they are typically only consider the part or component they work with. Companies succeed to some extent in educating their employees about their processes, however these are often the quality processes that are required to get ISO9000 accreditation. Success depends to a large extent upon who in the organisation shouts the loudest about processes. The design managers often have a better understanding of the process, but their understanding of details is typically limited to their personal focus of interest. Only senior technical managers, such as a vehicle architect or chief engineer for a

diesel engine, really understand the technical connectivity between components and between process steps that ultimately determines the success of any process. Many companies find it very difficult to recruit engineers with a good understanding of the entire product and all the issues involved in creating it.

2.2 Units of Planning

During the interviews and observations, designers and managers mentioned a multitude of different units of planning which they are concerned with. These are not independent and can often be quite easily translated into each other, however it is worth discussing them separately because they reflect the way people think about planning at a particular time in the process.

Quality units

Quality procedures such as APQP [5] or ISO9000/2001 [6] drive the process in many companies. They outline a set of milestones that the project and its documentation need to go through in order to be an auditable process. These milestones are generic and usually not tailored to the individual product or project.

Process units

Units of planning regarding the process fall into three types: time, resources and activities; these can be mixed in the actual units people think about:

- *Procedural milestones* are typically derived from the official “New Product Introduction Process” used in the company. Typically the NPI processes have 8 to 10 milestones, each with checklists of the requirements that need to be fulfilled and documents that need to be created. There is widespread awareness of procedural milestones, but for large projects these can lead to very coarse planning.
- *Lead-times for long lead-time items critically* influence the timing of a design process. Usually people know the target time and plan backwards to establish the latest time when long lead-time items need to be ordered.
- *Tasks for suppliers* structure the design process, because companies like to keep their supplier relationships simple. They therefore try to group the tasks that require interaction with a particular supplier, planning towards placing groups of orders.
- *Test schedules* are a vital driving force, because many products need to go through a pre-determined testing program to reach certifications. Others require on-going testing as part of the design process. In most companies testing resources are limited and designers need to book testing ahead of time. If testing slots are not met major delays can arise.
- *Resources* (including cost) determine what skills are available and affect when design tasks may be undertaken. At a high level in particular, resource availability and the resulting costs are the main planning drivers.
- *Activities* (including design times) are often used to plan processes on a detailed level; however, activities can only be planned over a fairly short time span because the activities required depend on the decisions made. This can be broken down in many different ways. Design activities are often closely linked to the product breakdown by components, for example, “design of the dashboard”.
- *Fire-fighting schedules* are localised plans to cope with on-going crises. They can be very ad-hoc and include a combination of the all above units of planning. However, they also become integral parts of other types of plan.

Product units

- *Cost (including design time)*: the cost of externally purchased components can easily be measured. Components designed and manufactured in-house have the design time factored into their manufacturing cost, as well as the time required to integrate externally purchased components. However, some cost plans only look at the cost of parts; Design time is not considered in manufacturing and assembly plans.
- *Bills of Materials* describe the parts purchased. This allows companies to keep track of the design process by the number of parts already defined. However this can be misleading because the breakdown of bills of materials is typically very uneven, modelling an engine and a screw at the same level.
- *Assemblies/Manufacturing*: the technology required to assemble components and the order in which they are assembled is vital for the financial success of a product. Hence activities and lead-time planning can be combined in terms of the manufacturing of the entire product or its components. For example, combining everything that is mounted to the chassis.

2.3 Types of Plan

In each company we found many types of different plans. Each plan only covered one project, rather than a range of projects. Some were general procedures that would be applied to any project regardless of its content or context, such as quality procedures or NPI processes. These procedures consist of generic steps, with the time allocated to some plans are detailed versions of others, while some are translations from different viewpoints. None of the plans are well suited to planing integration ofing projects and assessing multiple plans in parallel.

The plans are of course not independent. Figure 1 shows a map of different plans and their relationships. They can roughly be divided into quality plans, process plans and product plans. In some of the companies studied we found a strong prominence of quality plans, however these were totally isolated from any other form of plan and had to be pursued almost in parallel to other plans. Quality management was given very prominent role by top management in the organisation, but is often seen as a burden by designers and managers. The champions of the quality processes are sometimes quality experts with little technical expertise in any of these areas. In other companies, quality management is integrated in the new product introduction process and people show very little awareness of quality procedures.

Plans vary in the level of detail that they include. Process planning in most companies begins with making a *business case* for a new project. This includes rough estimates of time, cost and resources. Typically companies produce many business cases and only a very small number of them ever become projects, therefore their authors invest little time on each individual one and use very coarse estimates. However, if a business plan gets approved these values can easily become constraints for new projects, and hence can be viewed as a very general plan for a project. For example, a sports car project was planned around the details of the business plan, which had been conceived in about ½ a day each by its numerous authors. Before the beginning of the project, a time frame and a target cost is determined. This is based on the business plan or a slightly more detailed plan involving a conceptual design exercise. This time frame is used to work out the timing of individual stages of the *NPI process*, which typically includes a checklist of activities or document that need to be completed for each stage. The gateways are set based on experience and legal or certification requirements. At an equally high level a cost plan will be developed that determines the cost for main components. The gateways provide a definition of targets for other plans.

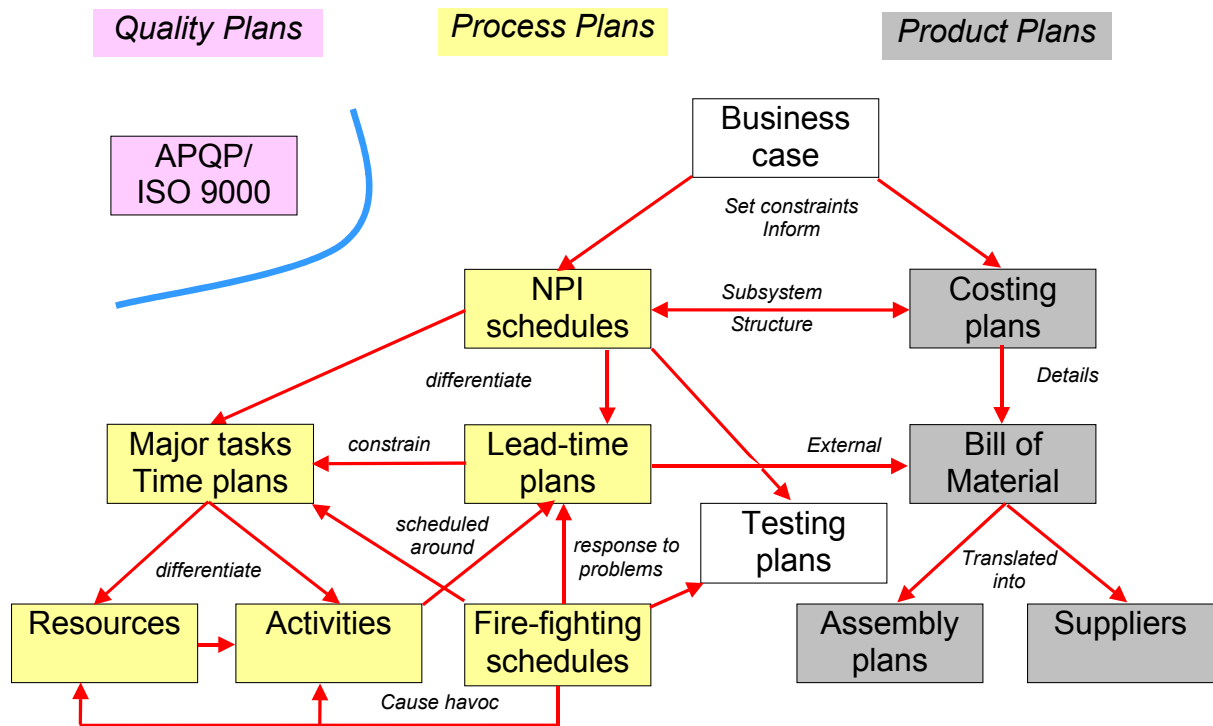


Figure 1. Types of Plans and their relationship

The *long lead-time items* will be identified early in the project, and decisions will be made as to which gateway they are required by. The long lead-time items set the time frame in more detail for the activities of teams and individuals, for example it takes 6 months for an airbag to arrive. It takes one month to define the interface to the airbag and provide a spec for it, and one month to integrate the airbag after delivery. This sets a time frame of 8 months for the design of the interior of the sports car. At the same time a testing schedule is worked out for the product, and slots are booked for test rigs. In most cases this is fairly generic for the type of product, so that the spacing of later parts of the NPI process are largely determined by test schedules.

The allocation of time and resources for development of major components and systems are often planned around the major lead-time items and the testing schedule. These *major task plans* are typically included in project reports. This enables the generation of *resource plans* for the entire project. The resource plans and the major task plans are not identical, because resources are moved between tasks according to requirements and availability.

The major task plans and the resource plans could be split up into *activity plans* for individuals, however activity planning often seems to be much more ad-hoc and short term. Activities are often only planned a few weeks ahead of time. This is a sensible response to the many unexpected developments in design projects. Much uncertainty in design is inherent and unavoidable, however much is also the result of ill considered planning. If problems occur in the process and gateways are threatened, designers and their managers go into fire-fighting mode. They generate short-term *fire-fighting schedules*. These involve an informal list of activities with little concern for other processes and their needs. Many designers openly comment that they really enjoy fire-fighting with clear constraints and open rewards, yet at the same time they feel that fire-fighting should not be necessary. Fire-fighting can cause havoc with resource plans, because people are appropriated from other parts of the organisation.

At the beginning of a project in parallel to the NPI process a *cost plan* is drawn up which sets the overall cost of the product. The overall cost is broken down into target costs for major components. This typically covers only the procurement of the parts, not the design cost involved in generating the parts. In consequence, often very costly changes are undertaken in order to minimise part cost. The part saving on a component would need to be enormous or very large sales expected to offset the cost a delayed new product introduction could bring.

Some companies see these cost plans as guidelines and are willing to exceed the cost slightly, others are very rigid about their target costs, so that increased costs in one component would have to be offset against savings in others. As the design progresses the *bill of materials* for the new product emerges. While this is the result of a design process, it has been included as a plan, because companies measure their performance against the bill of materials in deciding what percentage of the product is defined at any stage.

Other companies use old bills of materials as a starting point, providing a product breakdown which they can use to inform activity planning. As the final bill of materials emerges, manufacturing experts can begin to generate *assembly and manufacturing plans*. Similarly the emerging bill of materials and the lead-time plan are used to put suppliers' orders together, which again fits into the overall supply chain management.

Very recently, large organisations such as Airbus U.K. have begun to map out their own design processes in significant detail to capture and describe the process. They want to make processes more transparent to new designers, but also use them to inform planning. Currently, the plans have not gone far beyond the team that produced them. The effects that these plans will have on the overall organisation remains to be seen.

2.4 Owners of Plans

The different plans exist to meet the needs of different people in the organisation. Many people are aware of and handle more than one plan at a time. Figure 2 relates plans and their owners within an organisation, highlighting the complexity of process planning. The figure uses generic labels as the division of roles and the job titles vary from company to company, but a similar pattern emerges in each case. Individual participants could also be aware of more plans, but the figure concentrates upon the main plans. The dashed lines indicate the main focus of attention for each of the stakeholders. The * indicates where multiple instances exist. For example a project will have several team leaders working on different aspects of the product, but only one person responsible for accounting. Other groups, such as logistics or configuration management, also might get involved in the design process and hold their own version of bill of materials plans, however they are minor players in the planning of the design process.

The figure shows quite starkly several key aspects of process planning. Everybody is using more than one plan and most plans are used by more than one group of people. The project manager and the technical manager or most senior engineer have the greatest exposure to a wide variety of different plans. However, this is partly because the process plans are highly interrelated and only can be used fully when considered with awareness of other plans. The process manager rarely has detailed knowledge of the activities of individual teams, whereas the technical manager needs at least some awareness. He must also be aware of lead-times and testing, both for scheduling and for awareness of the outcome. Only the most senior engineers are involved in overall cost considerations and have exposure to the business case. Team leaders and engineers might be aware of the costs of their parts, but certainly not of other parts in the system. The engineering director who stands above a particular project would

typically be aware of the business case and the NPI schedule and would approve major milestones, but would not be involved in any details. Many organisations are organised in a matrix structure or component team, where function or component leader might be aware of the tasks and activities relating to their personal area.

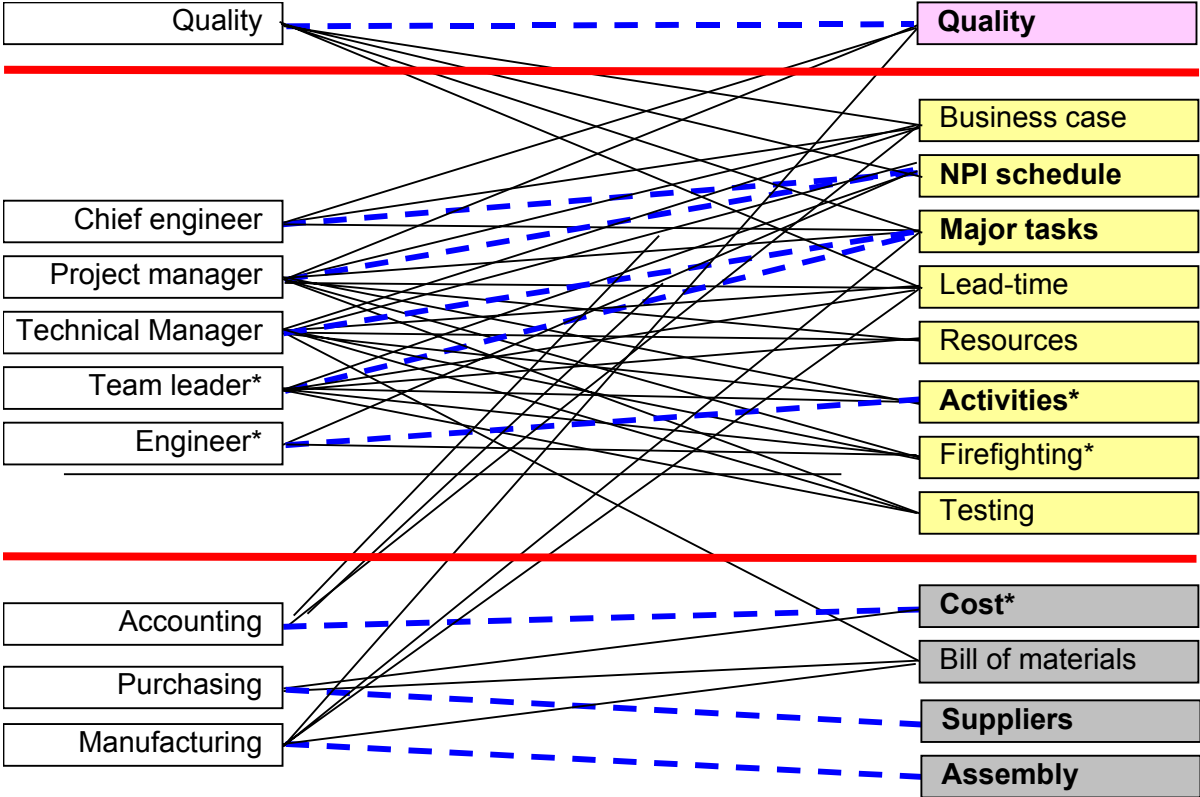


Figure 2. Plans and their Owners

There is a striking division between the designers and their managers and the other stakeholders in the company. Designers and design managers have very little awareness of the cost plans. They are provided with specific information and assessed against it. The project manager and the accountant work together directly, otherwise the accountants have little link to the technical content of the projects that they are assessing.

The involvement of manufacturing experts in the design process varies enormously between companies. Some use ‘manufacturing aware’ designers, while others place manufacturing experts into component design teams. However, all companies have specific plans, regarding the combination of individual components into products, aimed to understand the rework required to optimise manufacturing efficiency.

Quality plans seem to be quite isolated in most companies, where only higher management has a real awareness of them. Two companies we observed tried to use quality procedures as a main way of planning processes, in both cases with detrimental effects on the companies. In one it resulted in a Byzantine schedule of meetings, in the other most of the “planning”, was done retrospectively by adding amendments to quality plans once the work was completed or well in progress.

3 Effects of planning behaviour

This multitude of plans is very confusing for many ordinary designers and leaves room for interpretation at higher levels of the organisation. The plans work in most projects, because individuals have more than one plan at once and understand the relationship between the different tasks. For example, the technical manager knows the testing schedule and the major task plan, and can therefore consider the implication of a delay in testing on the overall design process, or the effect of a design change on testing in another project, even though these connections are never made explicit. No two individuals share an understanding of the process, and hence individuals make assumptions about plans that others do not share. Often the plans themselves are not accessible to many people in the organisation. They are discussed, but can't really be critiqued. For example, a team leader might be unable to understand the cost implication of a design decision, because he has little feeling for how tight the overall budget is.

3.1 Contingencies

Interrelated plans are also confusing because they handle contingencies differently. To some extent how much tolerance margin is included in a plan is dependent upon the personality and experience of the planner. For example, the sport car project almost had an ideology "no time for error", and most people claimed that no margin had been included. However, the vehicle architect had included time for design iterations in the original time estimates for the business case without ever making this explicit. The high-level product plans are very likely to include implicit margins, because designers and managers expect iterations. This can however be carried too far. We observed a young designer, who had drawn a major task plan for his boss which did not allow tapering out of boxes, as a staggered sequence with few overlaps. His boss changed this to a set of parallel lines, on the grounds all design is iterative; making the plan itself totally useless if arguably more honest. Product plans on the other hand do not include margins and try to discourage them as much as possible.

3.2 Lack of overview

In most companies planning is seen as a management activity that is well kept away from individual designers, who only know their personal tasks and the overall goals of the team. Milestones come down to them as deadlines, lead-times as problems. Whether the rationale behind planning decisions is explained to designers depends on the personality and availability of their line manager. Designers are occasionally confronted with major task plans and are shown Microsoft project plans, but they rarely construct these. No plan that we have seen makes the linkage between products and processes explicit. For example, the relationship between the cost of a part and the time it takes to design the part is often unknown, or similarly no method is in use to assess the cost in terms of time and resources associated with specific change alternatives. This lack of representation encourages people to push the linkage to the back of their mind; technical people neglect cost implications of processes, and financial people have no awareness of the financial implications of engineering decisions.

3.3 Communication Problems

Unclear plans are one of the main causes of communication difficulties. At the moment no plans capture the connectivity between tasks and components beyond the deliverable documents specified in the NPI process. Lack of understanding of the connectivity between tasks in a process or between components damages the information flow enormously (see [7]).

Figure 3 illustrates the communication paths in the sports car design project. In this company the quality managers had put a strong emphasis on quality procedures and prescribed a flurry of meetings for the senior members of the organisation. As designers had little awareness of the activities and needs of their colleagues, they were not able to communicate directly and proactively and fell back on formal communication paths through the management in the organisation. The problem was amplified in communication with other projects.

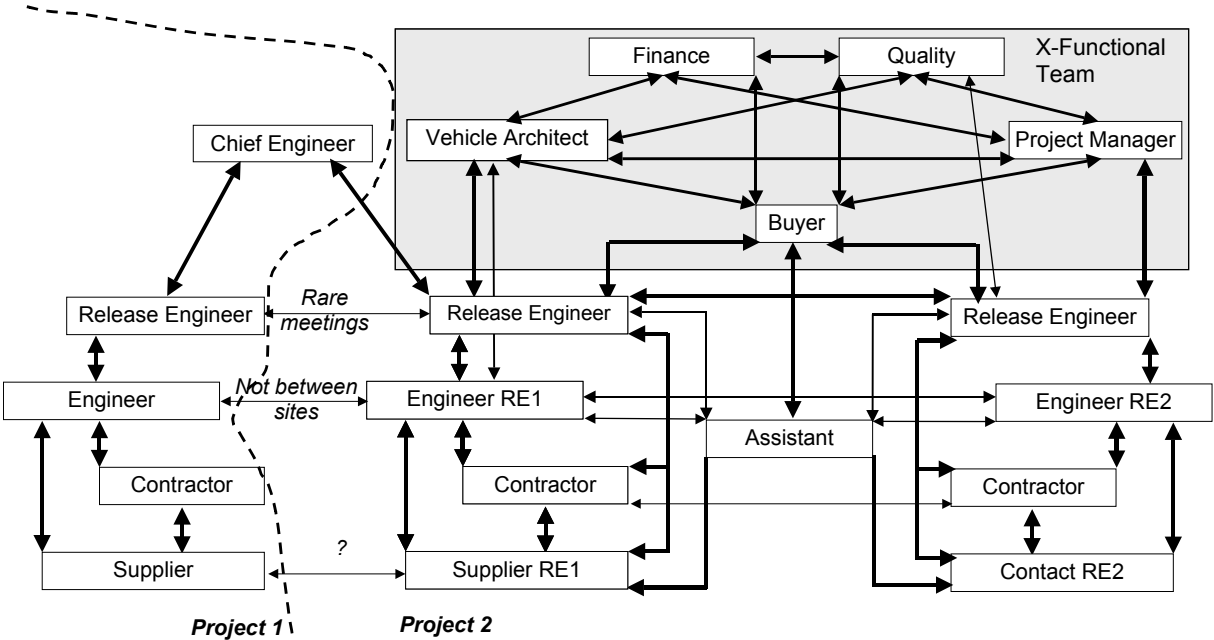


Figure 3. Communication within the project

4 Supporting Planning

The main problem with current planning behaviour is the lack of visibility and coherence between plans, forcing individuals to interpret the links based on their own experience. Some plans, such as a bill of materials, are not even recognised as such by some members of the organisation while they are vital for others. The opaque and ambiguous role of plans renders them open to abuse for political purposes. For example, designers might overbook or underbook on particular projects to influence their bosses' opinion of their efficiency. This deprives the company of a measure of their project success and the ability to plan ahead. Companies would benefit greatly from a better understanding of their own planning behaviour, and from the resulting increase in awareness of the role of certain plans.

As companies are beginning to recognise, planning can be supported through the generation of detailed master plans that incorporate much of the information contained in the existing plans into one coherent format. At the EDC in Cambridge we are developing the Signposting technique [8] which models processes through tasks, their input and output parameters and a qualifier indicating the minimal required maturity of the information that guarantees a certain quality of output. In addition, the models can contain probabilities and effects of task failure as well as cost and resources [9]. This enables risk assessment and route planning before the process, as well as analysis after the process, but is also visualises the plans and the assumptions behind it, so that it can be critiqued openly.

In summary, all the organisations studied used a multitude of plans, without a single detailed master plan. Successful execution depended on individuals reasoning about multiple plans. This resulted in a lack of overview of the product development and made product/process trade-offs very difficult. The efficiency of processes could be seriously improved through coherent, assessable and understandable plans.

Acknowledgements

The authors wish to thank the UK Engineering and Physical Sciences Research Council (grant GR/R64100/01) for funding this research

References

- [1] DTI, Successful Product Development, Department of Trade and Industry, UK, 1992
- [2] Browning, T. R., "Applying the Design Structure Matrix to System Decomposition and Integration Problems: A Review and New Directions." IEEE Transactions on Engineering Management, Vol.48(3), 2001, pp.292-306.
- [3] Bichlmaier, C.: 2000, *Methoden zur flexiblen Gestaltung von integrierten Entwicklungsprozessen*, Doctoral dissertation, Technische Universität München, München..
- [4] Eckert CM, Clarkson PJ and Zanker W "Change and customisation in complex engineering domains" Research in Engineering Design, in press.
- [5] APQP, "Advanced Product Quality Planning & Control Plan", Automotive Industry Action Group, Detroit, USA, 1994
- [6] Hoyle, D. "ISO9000 Quality Systems Auditor's Handbook", Butterworth-Heinemann, 1996.
- [7] Eckert, C.M., Clarkson, P.J. and Stacey, M.K., "Information Flow in Engineering Companies: Problems and their Causes" Proceedings of ICED'01 Design Management – Process and Information Issues Professional Engineering Publishing, Glasgow, 2001, pp. 43-50.
- [8] Clarkson, P.J. and Hamilton, J.R., "Signposting: a parameter-driven task-based model of the design process", Research in Engineering Design, Vol. 12, 2001, pp. 18-38.
- [9] Melo, A.F. and Clarkson, P.J., "Design process planning using a state-action model", Proceedings of ICED'01: Design Management – Process and Information Issues, Professional Engineering Publishers, Glasgow, 2001 pp. 345-352.

Claudia Eckert
Engineering Design Centre
University of Cambridge
Trumpington Street
Cambridge CB2 1PZ
United Kingdom
Tel. Int +44 1223 332 758
Fax. Int +44 1223 332 662
E-mail: cme26@eng.cam.ac.uk
URL: <http://www-edc.eng.cam.ac.uk/people/cme26.html>